

Ionizing Radiation Division	47020C	IRD-P-08
CALIBRATION OF $^{125}\text{I}$ or $^{103}\text{Pd}$ BRACHYTHERAPY SEEDS		

**Procedures for SP250 47020C (Calibration of  $^{125}\text{I}$  or  $^{103}\text{Pd}$  Brachytherapy Seeds), and 47021C (Each Additional  $^{125}\text{I}$  or  $^{103}\text{Pd}$  Seed of Same Design).**

**Purpose**

This procedure describes the calibration of brachytherapy seeds containing the radionuclides  $^{125}\text{I}$  or  $^{103}\text{Pd}$  in terms of air-kerma strength. The national air-kerma strength standard for low energy (< 50 keV) photon-emitting encapsulated sources is the Wide-Angle Free-Air Chamber (WAFAC).

**Scope**

$^{125}\text{I}$  or  $^{103}\text{Pd}$  seeds submitted for calibration must have air-kerma strengths within the range of  $0.5 \mu\text{Gy m}^2 / \text{h}$  to  $100 \mu\text{Gy m}^2 / \text{h}$ .

**Definitions**

Air-Kerma is the sum of the initial kinetic energies of all electrons liberated by photons in a volume element containing a given mass of air. The SI unit of air-kerma is the Gray (Gy), where  $1 \text{ Gy} = 1 \text{ J} / \text{kg}$ .

Air-Kerma Strength is the product of the air-kerma rate, *in vacuo*, at a distance *d* and the square of this distance. Air-kerma strength is typically expressed in units of  $\mu\text{Gy m}^2 / \text{h}$ , also represented by “U”.

Brachytherapy is a type of radiation therapy in which an encapsulated radioactive source is placed in or near a tumor or lesion.

Wide-Angle Free-Air Chamber (WAFAC) is a cylindrical, variable-volume ionization chamber used to directly realize the quantity air-kerma for low energy (< 50 keV) photon-emitting radioactive sources<sup>1</sup>.

**Equipment**

- WAFAC system hardware – includes ionization chamber with stepper motors for volume and position adjustment, motorized filter wheel (includes lead plug for leakage measurements and aluminum filters of various thicknesses), seed-mounting post with stepper motor for rotation of source about its axis, and a cathetometer for measuring the distance between the source and entrance aperture of the ionization chamber. (A procedure for construction of new Mylar electrodes is kept in a red loose-leaf notebook located beside the WAFAC control computer in room 245/B08.)
- High-voltage power supply (Bertan, Model 225, S/N 4207) to bias the ionization chamber.
- Electrometer (Keithley, Model 642, S/N 58461) and capacitor (General Radio Co., Model 1403-D, S/N 6265, calibrated by the NIST Electricity Division) to collect and measure liberated charge.

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- Temperature (Hart, Model 1504, S/N 97168) and pressure (Setra, Model Datum 2000, Ref. # R416) gauges to allow correction to reference conditions (22°C and 760 mm Hg).
- Computer with interface cards for data acquisition and instrument control, LabVIEW software, and WAFAC system control program (WAFAC\_15.vi).
- <sup>241</sup>Am source (R.S.# 00-0038) for periodic constancy check on ionization-chamber response.

### Health and Safety Precautions

Radiation Safety – Sources should always be handled with tongs, behind a leaded-plastic shield containing a tray to contain the source in case it is accidentally dropped. An audible survey meter must be kept within reach to ensure that the location of the source is known at all times. Finger dosimeters should be worn when manipulating a source. Great care should be used when handling a source, as excessive force could damage the encapsulation and cause leakage of radioactive material. When measurements are in progress, a sign designating the immediate area around the WAFAC system as a high-radiation area should be displayed, and the door to the laboratory should be locked. When a source is not in use, it should be placed in its lead pig and stored in the locked, lead-lined safe inside the locked WAFAC laboratory.

Electrical/Mechanical Safety – To avoid possible electric shock, one should not touch the ionization chamber when high voltage is applied. As the stepper motors controlling the ionization chamber volume and position, filter wheel position, and seed mounting post are controlled by the computer, they could move without warning. One should therefore avoid placing hands or objects near the motorized components of the system while they are turned on.

### Procedures

#### Acceptance of Sources

1. Sources must be shipped directly to NIST Health Physics for a contamination check upon arrival. (Health Physics must have a copy of the source manufacturer's radioactive materials license.) Sources showing evidence of leakage or shipping containers having detectable removable contamination in any manner will not be accepted for calibration.
2. A Report of Calibration Number (DG) should be obtained from the Radiation Interactions and Dosimetry Group office (245/C229) and entered into the WAFAC system control program prior to beginning the calibration of a source.

Environmental Conditions – Prior to taking any measurements, the temperature in the calibration laboratory (245/B08) is recorded. In order to proceed with the calibration, the temperature must be within the range (22 ± 3) °C.

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### Calibration Set-up

1. If the LabVIEW program WAFAC\_15.vi is not already running from the previous calibration, run it, re-homing the stepper motors for the ionization chamber and filter wheel.
2. Using tongs and a leaded-plastic shield, remove the seed to be calibrated from its lead pig and place it vertically on the seed-mounting post with the aid of the seed-mounting jig.
3. Remove the shield, then measure the distance between the center of the seed-mounting post and the front face of the WAFAC aperture using the cathetometer.
4. Enter the DG number, cathetometer readings, and the measurement parameters (number of measurement cycles, number and duration of leakage and exposure measurements, radionuclide, filter number) in the set-up screen of WAFAC\_15.vi. Note that actual parameters used depend on knowledge of approximate source strength supplied by the manufacturer and prior experience – use laboratory notebook for previous calibrations of similar sources as a guide.
5. Turn on source rotation (1 rpm) from the main screen of WAFAC\_15.vi, and visually verify that the seed is actually rotating.

### Calibration Sequence

1. Select “Start Sequence” from the main screen of WAFAC\_15.vi. A minimum of three measurement cycles should be completed.
2. Remove the seed from the post and holding it with spring-loaded tongs, rotate it  $\pi$  radians about the perpendicular bisector of the seed, flipping it end-for-end.
3. Remount the seed by placing it vertically on the seed mounting post with the aid of the seed-mounting jig.
4. Select “Start Sequence” from the main screen of WAFAC\_15.vi. A minimum of three measurement cycles should be completed.

### Analysis and Reporting of Results

1. A report page is printed out following each measurement cycle that contains a summary of the measurement parameters, ionization currents and their standard deviations, and the air-kerma strength of the source.
2. To combine the results of all measurements on a single source (a minimum of six cycles), the values of the measured ionization currents are entered by keyboard into an Excel analysis spreadsheet (Pd103WAFAC.xls for  $^{103}\text{Pd}$  seeds and I125WAFAC.xls for  $^{125}\text{I}$  seeds). The spreadsheet calculates an average value of air-kerma strength for the source, including uncertainty. This value is entered into the official calibration report, an example of which is given in Appendix A. (Note that a CD containing copies of these data analysis spreadsheet template files, as well as a copy of the WAFAC control program WAFAC\_15.vi and the  $^{241}\text{Am}$  quality assurance measurement history spreadsheet file Am241WAFAC.xls, is located beside the WAFAC control computer in room 245/B08.)

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WAFAC Quality Assurance

1. To verify constancy of the WAFAC over time, its response to an <sup>241</sup>Am source is periodically measured (approximately once per month) using the above procedures. The data is analyzed by keyboard entry into an Excel spreadsheet (Am241WAFAC.xls). The result of the <sup>241</sup>Am measurement is compared to the history of such measurements to verify that there are no changes in the sensitivity of the WAFAC over time. Deviations greater than 1% from the average of previous measurements should be investigated by repeating the measurement several times, noting any unusual behavior of the measurement system. If after repeated measurements of the <sup>241</sup>Am source the > 1% deviation continues to exist, the electrometer, thermometer, and barometer should be re-calibrated using the procedures given below.
2. To track the calibration results of a given seed design over time, the response of a well-ionization chamber to each WAFAC-calibrated seed is measured and a response coefficient equal to the quotient of the well chamber current and the air-kerma strength is calculated. Variations of up to ± 2% in the response coefficient are not uncommon due to source manufacturing variability and uncertainties in the WAFAC and well-chamber measurements themselves. Deviations greater than 2% from the average of previous measurements should be investigated.

Calibration of Electrometer – The following procedure should be used to re-calibrate the electrometer in the case of out-of-tolerance <sup>241</sup>Am source measurement results.

1. Connect a capacitor that has been calibrated by the NIST Electricity Division (ex. NBS B-15) between the Fluke Model 343A DC voltage calibrator (S/N 2195014) and the electrometer to be calibrated.
2. Allow both the electrometer and voltage calibrator to warm up for at least 2 hours.
3. Based on which coulomb scales of the electrometer are used when performing calibrations, select a series of test voltages to be used to calibrate the electrometer, taking into account the capacitance value of the NIST-calibrated capacitor. (A minimum of 5 data points per electrometer coulomb scale should be acquired.)
4. Select a voltage on the voltage calibrator and measure the accumulated charge on the capacitor with the electrometer.
5. Repeat step 4 until data is acquired for all relevant coulomb scales.
6. Calculate the calibration factor for each coulomb scale by taking the average of all ratios of the known accumulated charge to the charge indicated by the electrometer.

Calibration of Thermometer - The following procedure should be used to re-calibrate the thermometer in the case of out-of-tolerance <sup>241</sup>Am source measurement results.

1. Place the Hart Model 1504 thermometer probe and a thermometer that has been calibrated by the NIST Process Measurements Division (ex. Taylor S/N 3738041) in an insulated box (cardboard/Styrofoam).

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- Record the temperatures obtained from both thermometers periodically until a minimum of 5 data points are acquired.
- Calculate the calibration factor for the Hart thermometer by taking the average of all ratios of the known temperature to the temperature indicated by the Hart thermometer.

Calibration of Barometer - The following procedure should be used to re-calibrate the barometer in the case of out-of-tolerance <sup>241</sup>Am source measurement results.

- Place the Setra Model Datum 2000 barometer in close proximity to a barometer that has been calibrated by the NIST Process Measurements Division (ex. Wallace & Tiernan S/N XX11242).
- Record the pressures obtained from both barometers periodically until a minimum of 5 data points are acquired.
- Calculate the calibration factor for the Setra barometer by taking the average of all ratios of the known pressure to the pressure indicated by the Setra barometer.

### Evaluation of Measurement Uncertainties

WAFAC measurement uncertainties are determined based on the “Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results”<sup>2</sup>. The Type A component of uncertainty is equal to the standard deviation of the mean of replicate measurements. The Type B components are detailed in Appendix B. The combined standard uncertainty of the air-kerma strength calibration is equal to the square root of the quadratic sum of the Type A and Type B uncertainties, with a final reported expanded uncertainty obtained by multiplying the combined standard uncertainty by a coverage factor of two, representing an interval having a level of confidence of approximately 95%.

### Traceability of Measurements

The SI unit of air-kerma ( $K_{\text{air}}$ ) is the Gray (Gy), which is related to the quantity exposure (X) by multiplicative constants,  $K_{\text{air}} = X (W/e) / (1-g)$ , where  $W/e$  is the mean energy per unit charge expended in air by electrons, and  $g$  is the mean fraction of the energy of the secondary electrons that is lost to bremsstrahlung. (For the low-energy photons considered here,  $g$  is very small and set equal to zero.) Exposure is the total charge per unit mass liberated in free air by a photon beam (SI units of C / kg), and is directly realized by free-air chamber measurements, in this case by the WAFAC<sup>1</sup>. More detailed information concerning traceability and uncertainty analyses is summarized in reference 1 and SP250-19, available using the following hyperlinks:

<http://nvl.nist.gov/pub/nistpubs/jres/108/5/j85sell.pdf>

<http://ts.nist.gov/ts/htdocs/230/233/calibrations/Publications/series-pdf/SP250-19.pdf>

### Records

Descriptions of all measurements performed are recorded in an official NIST laboratory notebook that is registered in the Radiation Interactions and Dosimetry Group office

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(245/C229). Printouts from the WAFAC system computer that contain the results of each measurement are kept in a folder (stored in a file cabinet in room 245/C210) labeled with the source manufacturer's name, radionuclide, and month/year of calibration.

### References

1. Seltzer, Stephen M., Lamperti, Paul L., Loevinger, Robert, Mitch, Michael G., Weaver, James T., and Coursey, Bert M., New National Air-Kerma-Strength Standards for <sup>125</sup>I and <sup>103</sup>Pd Brachytherapy Seeds, *J. Res. Natl. Inst. Stand. Technol.* **108**, 337-358 (2003).
2. Taylor, Barry N., and Kuyatt, Chris E., Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, *National Institute of Standards and Technology Technical Note 1297*, 24 pages (Sep. 1994).

### Filing and Retention

The IRD Quality Manager shall maintain the original and all past versions of this IRD Procedure. Copies of the current revision of this Procedure shall be placed in controlled Quality Manuals. Electronic copies of this Procedure are uncontrolled versions.

All deleted Procedures (including old revisions) shall be maintained by the IRD Quality Manager. All old revisions shall be maintained until such time as it is decided to delete the Procedure. Once the decision has been made to delete the Procedure, only the last revision shall be maintained by the IRD Quality Manager.

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Appendix A – WAFAC Calibration Report

**National Institute of Standards and Technology**

**REPORT OF AIR-KERMA RATE  
MEASUREMENT  
FOR**

**Customer Name  
Address  
City, State, Country**

Seed Identification: **Model XXX**  
Arrival Date: **XX Month 20XX**  
SP250 Service ID # **47020C, 47021C**

Measurements performed by Michael Mitch

Report reviewed by Ronaldo Minniti

Report approved by Stephen M. Seltzer

For the Director  
National Institute of Standards and Technology  
by

Lisa R. Karam, Acting Chief  
Ionizing Radiation Division  
Physics Laboratory

Information on technical aspects of this report may be obtained from Michael Mitch, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460, Gaithersburg, MD 20899-8460, 301-975-5491. Report format revised 5/00. The results provided herein were obtained under the authority granted by Title 15 United States Code Section 3710a. As such, they are considered confidential and privileged information, and to the extent permitted by law, NIST will protect them from disclosure for a period of five years, pursuant to Title 15 USC 3710a(c)(7)(A) and (7)(B).



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**National Institute of Standards and Technology**

**REPORT OF AIR-KERMA RATE  
MEASUREMENT  
FOR**

**Customer Name  
Address  
City, State, Country**

Seed Identification: **Model XXX**  
 Arrival Date: **XX Month 20XX**  
 SP250 Service ID # **47020C, 47021C**

Description of seed provided by customer:

- Construction:**
- Diameter (mm):**
- Length (mm):**
- Half-Life(d):**
- Isotope:**
- Purity rating:**

**NIST Reference time and date:** 00:00:01 EST, XX Month 20XX  
**Temperature range during measurements:** XX °C to XX °C  
**Pressure range during measurements:** XXX mmHg to XXX mmHg

Measurement Results

Source ID No.	Number of Measurements	Air-Kerma Strength (μGy m <sup>2</sup> /h) at 295.15 K (22 °C) and 101.325 kPa (1 Atm)	Reproducibility <sup>a</sup> (%)	Expanded Combined Relative Uncertainty <sup>b</sup> (%)

<sup>a</sup> Obtained from the replicate measurements as the standard deviation of the mean.

<sup>b</sup> See page 3 for note on uncertainty.



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## Explanation of Terms Used in the Calibration Procedures and Tables

**Air-Kerma Strength:** The air-kerma strength is the product of the air-kerma rate and the square of the distance to the reference point assumed in vacuum, in a direction perpendicular to the long axis of the cylindrical encapsulated brachytherapy source. For more details see *Specification of Brachytherapy Source Strength*, Report 21 of the American Association of Physicists in Medicine, Am. Inst of Phys., MD, June 1987.

The measured air-kerma strength is obtained from:

$$S_k = (W/e) I_{\text{net}} d^2 \Pi_i k_i / (\rho_{\text{air}} V_{\text{eff}})$$

where

$$W/e = 33.97 \text{ J/C}$$

$\rho_{\text{air}}$  = air density

$I_{\text{net}}$  is the net current (background and leakage subtracted)

$d$  is the source-to-aperture distance

$V_{\text{eff}}$  is the effective detector volume

$\Pi_i k_i$  is the product of the correction factors to be applied to the measurement

**Measurement Geometry:** The measurements were performed with a wide-angle free-air chamber whose aperture, 8 cm in diameter, is located at a nominal distance of 30 cm from the seed axis. This arrangement thus effectively averages the air-kerma rate within a cone whose half-angle is approximately 8°. Any contribution to the measurement from titanium x-rays, produced in the encapsulation, has been eliminated by the use of an appropriate absorber. To mitigate possible geometric anomalies and source non-uniformity, each seed was rotated about its long axis during a measurement, and reversed end-for-end for each successive measurement.

**Uncertainty:** The combined standard uncertainty assigned to these results has been evaluated as the square root of the quadratic sum of the component standard uncertainties, including those evaluated by statistical means (Type A) and those evaluated by other means (Type B). The expanded uncertainty has been obtained by multiplying the combined standard uncertainty by a coverage factor of two, to represent an interval having a level of confidence of approximately 95%.

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**Appendix B – Relative Standard Uncertainties in the Determination of Air-Kerma Strength  $S_k$  for  $^{125}\text{I}$  and  $^{103}\text{Pd}$  Brachytherapy Seeds Using the Wide-Angle Free-Air Chamber**

Estimated relative uncertainties ( $1\sigma$ ) are given in percent, and include the type A uncertainty  $s_i$  estimated by statistical methods, and the type B uncertainty  $u_j$  estimated by other means.

	$^{125}\text{I}$		$^{103}\text{Pd}$	
	$s_i(\%)$	$u_j(\%)$	$s_i(\%)$	$u_j(\%)$
net current, $I_{\text{net,diff}}$	$s_I$	0.06	$s_I$	0.06
$W/e$	-	0.15	-	0.15
air density, $\rho_{\text{air}}$	-	0.03	-	0.03
aperture distance, $d$	-	0.24	-	0.24
effective chamber volume, $V_{\text{eff}}$	0.11	0.01	0.11	0.01
decay correction, $k_1$	-	0.02 <sup>a</sup>	-	0.08 <sup>a</sup>
recombination, $k_2$	-	0.05	-	0.05
attenuation in filter, $k_3$	-	0.61 <sup>b</sup>	-	0.51
air attenuation in WAFAC, $k_4$	-	0.08 <sup>b</sup>	-	0.10
source-aperture attenuation, $k_5$	-	0.24 <sup>b</sup>	-	0.31
inverse-square correction, $k_6$	-	0.01	-	0.01
humidity, $k_7$	-	0.07	-	0.07
in-chamber photon scatter, $k_8$	-	0.07	-	0.07
source-holder scatter, $k_9$	-	0.05	-	0.05
electron loss, $k_{10}$	-	0.05	-	0.05
aperture penetration, $k_{11}$	-	0.02	-	0.08
external photon scatter, $k_{12}$	-	0.17	-	0.19
<b>Combined uncertainty</b>	$(s^2_I + 0.762^2)^{1/2}$		$(s^2_I + 0.728^2)^{1/2}$	

a) Assuming time from reference date is no more than ~15 days.

b) Including spectral variations due to possible Ag K x rays.

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